VI. — On the Average Composition of British Igneous Rocks.

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THE subject of the average composition of collections of rocks has been dealt with in a paper published ten years ago by Mr. F. W. Clarke on "The Relative Abundance of the Chemical Elements."[1] The object of that paper was to arrive at an estimate of the mean chemical composition of the earth's crust, but incidentally the author shows a close correspondence between the mean compositions of groups of miscellaneous rocks from different regions. It appears from his figures that a moderate number of analyses—less than a hundred—if taken without any selection, is enough to give value to their mean. It may therefore be of interest to apply the method to our own country. I have accordingly collected published analyses of 397 British igneous rocks, viz., 195 English, 31 Welsh, 79 Scottish, and 92 Irish, and calculated their mean. By searching it would doubtless be possible to find additional analyses, though probably not many, and the number taken is quite sufficient for our purpose. I have taken all the complete analyses that I found, except a very few known to be faulty, since it is the essence of the statistical method that no selection should be exercised. Partial analyses I have not used, with the exception of 78 analyses of Malvern rocks by Timins, in which the alkalies were not estimated. The mean given by the 397 analyses (or in the case of the alkalies by 319) appears in Column I.

	I. British Rocks.	II. British Rocks (corrected).	III. American Rocks.
SiO_2 ...	58·75	58·46	59·77
TiO_2 ...	0·12	0·69	0·53
Al_2O_3 ...	15·64	15·13	15·38
Fe_2O_3 ...	5·34	5·34	2·65
FeO ...	2·40	2·40	3·35
MnO ...	0·15	0·40	0·09
MgO ...	4·09	3·84	4·40
CaO ...	4·98	4·98	4·81
Na_2O ...	3·25	3·25	3·61
K_2O ...	2·74	2·74	2·83
H_2O ...	2·23	2·23	1·51
P_2O_5 ...	0·02	0·25	0·21
	99·71	99·71	99·14

These figures, however, need some corrections for various reasons. In particular, certain constituents have not been determined in all cases. Titanic acid was estimated in 30 analyses only and recorded as 'traces' in 4 others. The mean for the 34 rocks is 1·39. This is doubtless too high a figure to be inserted in the general average, because titanic acid has usually been sought in such rocks (chiefly of basic and ultra-basic composition) as were expected to yield it in noteworthy quantity. Since some arbitrary assumption is

[1] Bull. Phil. Soc. Washington, vol. xi (1889), pp. 131–142; also in *Chemical News* for Jan. 17, 1890.

necessary, I have halved the figure, and taken the titanic acid as 0·69 per cent. The difference between this and 0·12 is to be subtracted from the silica and alumina, and half has been taken from each. The same reasoning does not apply, at least in the same degree, to manganese and phosphoric acid. Manganous oxide was estimated in 103 analyses and recorded as traces in 51. The mean for these 154 rocks is 0·40, and this figure may be adopted in the general average without fear of much error. The difference between 0·40 and 0·15 is to be subtracted from the magnesia. Phosphoric anhydride was estimated in 35 analyses only and recorded as traces in 20. The mean for these 55 rocks is 0·25, and this figure may be adopted in the general mean, the difference between this and 0·02 being accordingly subtracted from the alumina. The result as thus corrected is seen in column II. In the paper already cited Clarke gives the mean analysis of 880 miscellaneous rocks, American and others; but I quote for comparison, instead of this, a mean analysis of American rocks exclusively, given in a later work by the same author.[1] This, which is calculated from 680 complete analyses, supplemented by a number of partial analyses, is given in column III.

There are still certain points to be observed in comparing the two columns. In 157 of our 397 analyses ferrous oxide was not estimated. The figure for this constituent is therefore too low and that for ferric oxide correspondingly too high. Again, the water has not always been estimated in the same way. In many of the analyses only the loss on ignition has been determined, and by taking this as water I have no doubt increased unduly the figure for that constituent. Carbonic acid, chlorine, fluorine, and sulphur, when separately estimated in the analyses, have been discarded. These, of which only the first is of importance, are therefore partly included, together with 'loss' and errors, in the 0·29 per cent. required to make up the total to 100. This defect should really be somewhat greater, since a certain amount of ferrous oxide has been reckoned as ferric.

The British mean is seen to have a rather lower silica-percentage than the American, though it agrees closely enough with the figure (58·59) in Clarke's old mean for rocks from various quarters of the globe. The difference is perhaps not a significant one. As regards titanic acid and alumina, the two columns show a fair correspondence. The British rocks are evidently richer in iron than the American. The proportions of the two oxides are, as has been remarked, not correct, and it is not possible to rectify them; but converting the whole to ferric oxide, we get 8·01 for column II, as compared with 6·37 for column III. The relatively high percentage of manganese in the British rocks is certainly of significance, and must be regarded as a characteristic of the whole assemblage. The precise figure is not to be insisted upon, since it has been reached in a rather arbitrary fashion; but even in column I, where all rocks in which manganese had not been recorded were assumed to contain none, the

[1] Clarke & Hillebrand, "Analyses of Rocks": Bull. 148, U.S.G.S., 1897.

figure is very distinctly higher than Clarke's. We see next that the British rocks are poorer in magnesia, and rather poorer in soda than the American, while in lime and potash the two columns show no great disparity. The alkalies jointly amount to 5·99 in the one column as compared with 6·44 in the other. We might have anticipated a greater deficiency in alkalies in the British rocks, and also a more marked excess of lime, as compared with the American, since the majority of our rocks belong decidedly to what Iddings has styled the 'Sub-Alkali' rather than to the 'Alkali' group, while both groups are well represented in the United States. The apparently rather large percentage of water in column II must be due in part to the circumstances already noted. In phosphoric acid there is a sufficiently close agreement between the two averages.

If we were to separate the English, Scottish, and Irish rocks, and calculate averages for the several groups, we should find that these would be disturbed by principles of selection which have entered into the choice of the rocks analyzed. Thus we have a large number of analyses of Irish granites by Professor Haughton, while the Scottish granites have been comparatively neglected. This goes to make the Irish average more acid and the Scottish more basic than the general mean. Nevertheless, it would no doubt be possible to get results of interest for even smaller areas, provided that rocks sufficiently various in kind are included; and, if we take account of partial as well as complete analyses, we shall find for some areas a considerable body of data. For example, 96 igneous rocks from the English Lake District give a mean silica-percentage 58·75, not very different from that of the general average; but 82 examples from the Malvern Hills give only 54·81. The low figure in the latter case can scarcely be accidental. It is worthy of note, too, that of 78 igneous rocks from the Malverns, Timins estimated copper oxide in 21 and recorded traces in 11 others, the mean percentage being 0·23 for these 32 rocks, or 0·12 for the whole 78. This is at least twenty times as great as any probable estimate for the general average of rocks.

The mean specific gravity of a large number of igneous rocks from a given district will probably be found in some cases to be characteristic. Of the 397 analysed British rocks included above, specific gravities are given for 209, the mean value being 2·777. By including 527 miscellaneous igneous rocks from various districts of Britain, we find the mean specific gravity of the whole 736 to be 2·763. Taking the two special districts already mentioned, we find that 113 Lake District rocks give a mean specific gravity 2·737, decidedly below the average, while 38 from the Malverns give 2·841, which is decidedly above the average. The preponderance of basic rocks in Skye comes out less strikingly, 332 miscellaneous igneous rocks from that island giving a mean of 2·774. In all such calculations it is of course essential that no selection should be exercised, the rocks being taken at random so as fairly to represent the variety found within the district.